Terrestrial Drift Fences With Pitfall Traps: An Effective Technique for Quantitative Sampling of Animal Populations

J. WHITFIELD GIBBONS AND RAYMOND D. SEMLITSCH
Savannah River Ecology Laboratory,
Drawer E, Aiken, South Carolina 29801

ABSTRACT.— The terrestrial drift fence with pitfall traps is a commonly used technique to collect and quantitatively sample populations of certain vertebrate and invertebrate species. However, a variety of limitations, advantages, biases, and contingencies must be considered to use the method most effectively. The best materials to use for these fences and traps have been aluminum flashing and plastic 20-liter buckets. Aluminum flashing is rigid and does not deteriorate with age. Large plastic buckets permit the capture of many species that can escape from small can traps. Maintenance, such as filling cracks or holes along the fence, bailing water from traps, and mowing vegetation alongside fences, are necessary for continued effectiveness. Initial cost of construction is high, both in time and money; however, drift fences are cost effective for most ecological studies. Biases result primarily from variation in morphology, ecology, and behavior of species, or as a consequence of design and the manner in which the drift fence is checked and maintained.

INTRODUCTION

The terrestrial drift fence and pitfall trap technique has been used for many years for field sampling a variety of vertebrate and invertebrate species (e.g. Imler 1945; Gloyd 1947; Woodbury 1951, 1953; Storm and Pimentel 1954; Packer 1960; Husting 1965; Shoop 1968; Hurlbert 1969; Gibbons 1970; Gibbons and Bennett 1974; Briese and Smith 1974; Randolph et al. 1976; Collins and Wilbur 1979; Bennett et al. 1980; Brown 1981; Wygoda 1981). The use of pitfall traps (without drift fences) in the study of invertebrates was reviewed by Mitchell (1963) and Greenslade (1964); however, no thorough assessment of the drift fence technique has been presented (but see Storm and Pimentel 1954). Our purpose is to discuss the advantages as well as the limitations of the approach, using examples from 13 years of data taken on reptiles and amphibians collected on the U. S. Department of Energy's Savannah River Plant (SRP) near Aiken, South Carolina.

CONSTRUCTION OF DRIFT FENCES

Basic design for a terrestrial drift fence is a straight fence extending slightly below ground and up to 50 cm high, with pitfall traps placed alongside the fence and buried flush with the ground at prescribed intervals (Fig. 1A). The intent is to intercept animals traveling overland so that upon encountering the drift fence they turn left or right and continue along the fence until they fall into a trap.

Fences and traps used on the SRP have undergone a 13-year evolution of construction materials and design (Fig. 1B,C,D). The earliest drift fences, constructed in 1968 of chicken wire, were intended only for capture of turtles moving overland. Twenty-liter (5-gallon) metal paint buckets served as pitfall traps. From 1969 to 1971, hardware cloth (¼-inch mesh) was used for fencing material. We have subsequently found the most effective material to be 50 cm high aluminum flashing, of which approximately 10 cm is placed below the surface of the ground. This has the advantage of preventing small animals from passing under or through the fence, or larger ones from using the mesh to climb over. The flashing is also considered to be superior to various plastic fencing materials used by other investigators (Storm and Pimentel 1954; Packer 1960; Husting 1965; Shoop 1974; Gill 1978; Wygoda 1979; Douglas 1979; Collins and Wilbur 1979) in that it is not easily torn or pushed down by larger vertebrates such as turtles, alligators, feral pigs, or deer. Furthermore, aluminum flashing does not rust or deteriorate with age as do many other commonly used fence materials.

Twenty-liter plastic buckets have proved to be the most effective pitfall traps. These containers are relatively permanent, whereas metal buckets begin to deteriorate within two years, making them less useful for long-term studies. Although smaller volume traps (# 8 cans) have been used effectively for certain species (Shoop 1965; Gill 1978; Douglas 1979), larger traps permit the capture of many species that can easily escape from a shallow can.

MAINTENANCE

Once drift fences and pitfall traps have been constructed, maintenance is required for continued effectiveness. Vegetation growing alongside the fence should be mowed or cut to prevent animals from using it to climb over, as well as to assure visibility in checking traps and fence margins. Mowing chores can be reduced in some situations by placing a heavy layer of sand alongside the fence, extending out 5-10 cm.

Cracks or crevasses may develop along the fence or around buckets following construction, particularly after heavy rainfalls. They should be filled to prevent animals from using them as tunnels under the fence. Pitfall traps often fill and overflow with water after heavy rains or from rises in groundwater. Holes drilled in the bottom or sides will prevent water accumulation in some instances, although on certain occasions bailing may be necessary.

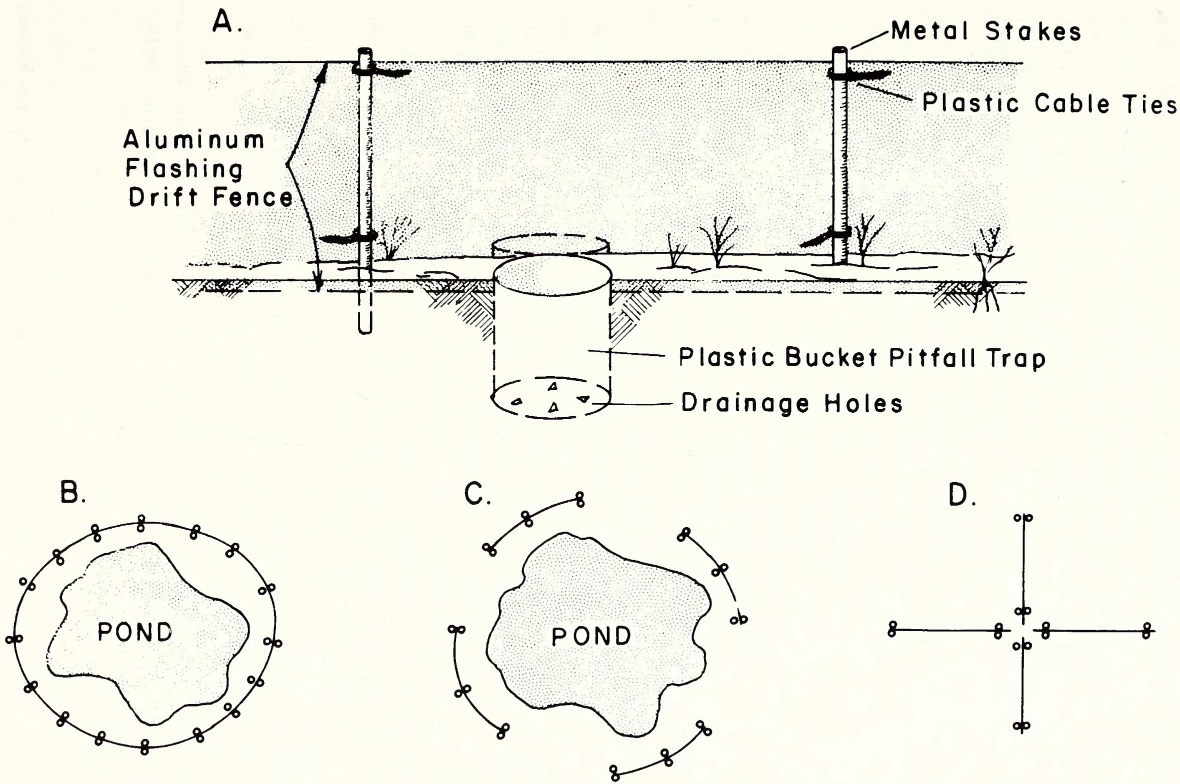

Fig. 1. The basic design for a terrestrial drift fence with pitfall traps, and spatial arrangements. A, cross section. B, top view of a continuous fence. C, top view of a partial fence. D, top view of a plus-shaped fence array.

In addition to the hazards of too much water, traps must be checked at frequent intervals to avoid desiccation, predation, and other problems that can arise. In sampling amphibians, desiccation can be avoided at most times of the year by a daily checking schedule. A more frequent checking routine, or use of wet sponges in the bottom of traps, can prevent desiccation or lessen heat stress during summer. Reptiles and mammals are typically more resistant to desiccation and can remain in pitfall traps for longer periods of time than amphibians.

The probability of predation on animals in pitfall traps increases the longer they go unchecked, hence checking at several day intervals would not be desirable in most instances. Daily checking is recommended under most circumstances, although more frequent checking (i.e., two or three times a day) may be necessary during mass migration of amphibians from breeding ponds, or when prolonged disruption of the animals' activity is detrimental. Use of an electric wire system designed to safeguard each pitfall trap is effective in deterring most mammalian predators except shrews (C. R. Shoop, pers. comm.).

TIME, COST, AND EFFORT TO CONDUCT A STUDY

Drift fences with pitfall traps yield a wealth of biological information, often providing ecological perspectives that could be obtained in no other manner. However, the cost in labor and materials can be great. The time investment in an effective drift fence operation can be partitioned into construction, maintenance, and operation (Table 1). Initial cost of construction is high, both for materials and in time required for installation. After construction, the cost for materials is small; however, the time investment can become onerous if the traps are checked in an effective manner, such as daily (Table 1).

Although the time and effort put into drift fence construction, maintenance, and operation are high, data accumulation is often superior to any other form of collecting for a wide variety of terrestrial animals, particularly amphibians (Fig. 2; Table 2). The technique is highly cost effective once the critical investment level has been reached. This is especially true for long-term ecological studies where continuous daily hand sampling is impractical.

INTERPRETATION OF RESULTS

Drift fences with pitfall traps yield large amounts of data on numbers (often total population sizes), seasonality, migration patterns, diversity, and distribution patterns of many animals (see references in Introduction; Table 2). Some species are collected in high numbers that closely represent the actual population size, whereas the proportional capture of others is below that of their actual abundance. However, as

Table 1. Categorization of time, labor, and expenses for materials for various stages of drift fence construction, maintenance and operation for two study sites on the Savannah River Plant.

Category	Sites	
	Rainbow Bay	Sun Bay
Date constructed	September 1978	February 1979
Circumference (m of fencing)	440	450
Number of pitfall traps	88	90
Construction costs:		
total labor (man hours)	168	119
aluminum flashing (@$22/roll)	$660	$682
buckets (obtained at no cost)	0	0
stakes (180/fence obtained at no cost)	0	0
plastic cable ties (400/fence)	$10	$10
shovels, axes, sledge hammer	$80	$80
Maintenance costs (hr/yr):		
cut grass around fence	5	5
check and fill cracks and holes, replace sponges, renumber pitfall traps, and other routine maintenance	4	4
Operation (hr/yr):		
daily checking of pitfall traps and processing animals (not including transportation)	365	365

with any sampling technique, certain biases and limitations must be taken into account in the interpretation of data. Biases are primarily due to variation in morphology, ecology, and behavior of species, or are a consequence of fence design and the manner in which it is checked and maintained.

A species' morphology is an obvious factor in determining the effectiveness of the technique in capturing certain animals. The large body size of some snakes and mammals permits ready escape from the pitfall traps, as does an ability to climb or jump over the fence. Climbing or burrowing adaptations, such as toepads on treefrogs or the digging limbs of moles, can reduce the proportion of the population that is actually sampled.

Behavior can also influence the capture of certain species. For example, although many specimens of the eastern box turtle, *Terrapene*

Table 2. Direction of movement of all vertebrate species captured (original and recaptured) in drift fence and pitfall traps at Rainbow Bay and Sun Bay on the Savannah River Plant, South Carolina, for one year (1 April 1979-31 March 1980).

Species	Rainbow Bay				Sun Bay			
	Entering		Exiting		Entering		Exiting	
	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.
Class Amphibia								
Order Caudata								
Ambystoma talpoideum	1,750	154	449	3,856	6,028	0	938	0
Ambystoma opacum	8	1	3	0	21	0	19	0
Ambystoma tigrinum	129	46	42	992	57	1	4	1
Notophthalmus viridescens	1,625	968	609	15,013	3,452	5	2,100	23
Plethodon glutinosus	65	2	49	7	22	0	24	0
Pseudotriton ruber	2	0	4	0	3	0	0	0
Pseudotriton montanus	0	0	0	0	1	0	0	0
Eurycea quadridigitata	374	30	56	6	11	0	2	0
Eurycea bislineata	1	0	0	0	0	0	0	0
Order Anura								
Scaphiopus holbrooki	69	33	39	34	1,803	134	483	58
Bufo terrestris	424	644	79	689	580	375	98	622
Bufo quercicus	0	0	0	0	0	0	1	0
Acris gryllus	12	0	3	0	16	1	3	1
Hyla cinerea	0	1	0	0	0	0	0	0
Hyla crucifer	346	212	205	1,329	594	12	239	50
Hyla gratiosa	2	10	44	161	4	0	0	1
Hyla femoralis	6	11	8	11	2	0	1	0
Hyla chysoscelis	0	4	1	1	7	3	1	2
Pseudacris nigrita	251	18	49	182	12	0	3	1

Pseudacris ornata	235	28	89	1,158	392	9	79	18
Gastrophryne carolinensis	1,122	18	418	15	887	1	420	0
Rana catesbeiana	4	20	5	101	8	81	2	0
Rana clamitans	27	30	19	1,136	27	35	1	7
Rana utricularia	699	2,024	610	52,287	154	29	24	7
Rana areolata	0	0	0	0	2	0	0	0
Class Reptilia								
Order Chelonia								
Chelydra serpentina	2	0	1	0	5	1	0	2
Sternotherus odoratus	1	0	2	0	0	0	0	0
Kinosternon subrubrum	29	6	25	6	49	59	14	11
Terrapene carolina	1	0	1	0	1	0	0	0
Pseudemys scripta	2	1	0	1	1	0	1	0
Deirochelys reticularia	8	9	10	2	14	14	4	1
Order Squamata								
Suborder Sauria								
Anolis carolinensis	26	2	19	2	5	0	12	0
Sceloporus undulatus	18	1	8	3	9	3	5	6
Cnemidophorus sexlineatus	2	2	1	0	19	7	19	2
Scincella laterale	4	2	14	0	3	1	2	1
Eumeces fasciatus	1	0	0	0	0	0	0	0
Eumeces laticeps	0	0	0	0	0	0	1	0
Eumeces inexpectatus	1	0	0	0	0	0	0	0
Ophisaurus ventralis	1	0	0	0	0	0	0	0
Ophisaurus attenuatus	0	0	1	0	0	0	1	0
Suborder Ophidia								
Nerodia erythrogaster	2	0	2	0	0	0	0	0
Nerodia fasciata	10	1	2	0	1	2	3	1
Storeria dekayi	1	0	4	0	2	0	0	0

Storeria occipitomaculata	26	1	37	0	4	0	2	0
Thamnophis sirtalis	2	1	5	1	1	0	0	0
Thamnophis sauritus	3	0	3	1	0	0	0	0
Diadophis punctatus	7	2	10	0	7	1	15	3
Farancia abacura	2	1	3	0	0	0	0	0
Elaphe obsoleta	1	0	0	0	0	0	0	0
Lampropeltis getulus	1	0	0	0	0	0	2	0
Heterodon platyrhinos	2	0	1	0	0	0	2	1
Heterodon simus	0	0	1	0	2	0	1	0
Coluber constrictor	13	1	8	1	4	2	7	0
Cemophora coccinea	4	0	1	0	5	0	6	0
Tantilla coronata	17	0	11	0	42	0	46	0
Virginia striatula	0	0	0	0	0	0	1	0
Virginia valeriae	1	0	0	0	0	0	0	0
Agkistrodon piscivorus	2	0	2	0	0	0	0	0
Crotalus horridus	0	0	1	0	0	0	0	0
Pituophis melanoleucus	1	0	0	0	0	0	0	0
Class Mammalia								
Order Insectivora								
Sorex longirostris	17	1	11	0	0	0	1	0
Blarina brevicauda	68	1	40	0	26	0	20	0
Cryptotis parva	3	0	2	0	5	0	0	0
Unidentified shrews	26	1	17	0	7	0	11	0
Scalopus aquaticus	1	0	0	0	0	0	0	0
Condylura cristata	3	0	0	0	0	0	0	0

Order Rodentia								
Peromyscus polionotus	0	0	1	0	7	0	1	0
Peromyscus gossypinus	1	0	0	0	2	0	3	0
Reithrodontomys humulis	16	0	146	8	1	0	0	0
Ochrotomys nuttalli	5	0	3	0	3	0	3	0
Sigmodon hispidus	7	0	14	0	5	0	18	0
Microtus pinetorum	8	0	3	0	9	0	1	0
Unidentified mice	11	0	13	0	9	0	3	0
Neotoma floridana	0	0	0	0	0	0	1	0
Order Lagomorpha								
Sylvilagus floridanus	2	0	1	1	2	1	1	1
TOTALS	7,509	4,292	3,250	77,004	14,333	777	4,641	819

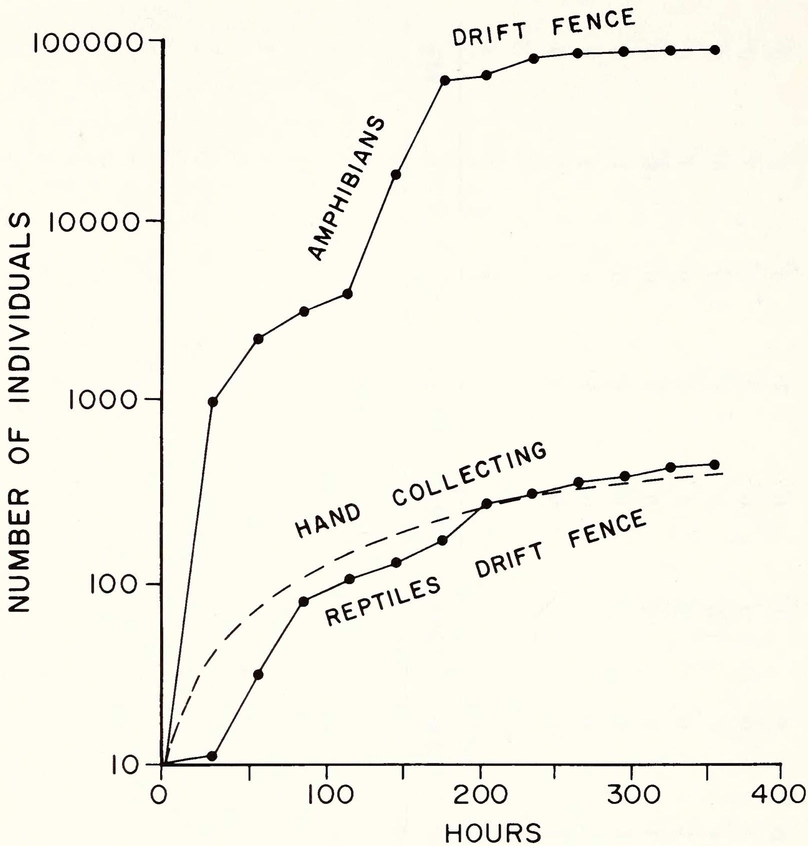

Fig. 2. Comparison between hand collecting and drift fence methods. X-axis represents cumulative man-hours (time investment in fence construction not included). The dashed curve for hand collecting indicates cumulative number of specimens of either reptiles or amphibians (specimens/hour yields were similar). The dashed curve is based on field notes of "best-case" general collecting by experienced herpetologists in typical southeastern Coastal Plain terrestrial habitats during spring or summer. Data points on drift fence curves indicate cumulative numbers obtained at monthly intervals (approximately 35 hours each) during a complete year of sampling, beginning January 1979 at Rainbow Bay. These data, in constrast to hand collecting, include winter days when reptiles would not ordinarily be sought by hand collectors.

carolina, have been collected alongside drift fences, few adults have actually fallen into the traps. This is presumably the result of this highly terrestrial species' awareness of topographic relief and an avoidance of natural pitfalls. When some specimens of the Appalachian woodland salamander, *Plethodon jordani*, encounter a drift fence, they will turn around and return to their original retreat, and subsequent forays might be in other directions (C. R. Shoop, pers. comm.). Such behavior could bias interpretations of direction preferences.

Ecology of a species is probably the most important factor influencing the rates and patterns of capture. Home range size and migratory movements are critical in certain species. For example, the mole salamander, *Ambystoma talpoideum*, has a life cycle in which adults, under most conditions, characteristically migrate to a breeding pond during winter and return to land in early spring. Juveniles exit the pond a few months later (Patterson 1978; Semlitsch 1981). Therefore, any fence placed parallel to the edge of the breeding pond will capture most, if not all, salamanders moving through the area sampled.

Southeastern crowned snakes, *Tantilla coronata*, or scarlet snakes, *Cemophora coccinea*, may occur in the same habitat as *A. talpoideum*. However, individual home ranges in these two species of snakes are independent of the orientation and distance to water, so that movement primarily represents daily activity patterns. Although either species of snake may be captured in relatively large numbers in pitfall traps (Nelson and Gibbons 1972; Semlitsch et al. 1981), the drift fence will only reveal that part of a population whose home ranges overlap the fence system. Thus, whether or not a study species has a congregating focal point as part of its life cycle will influence the effectiveness of the technique in assessing population size.

Similarly, use of drift fences around an aquatic habitat to monitor terrestrial movement of turtles will result in capture of a higher proportion of some species than others. The propensity of eastern mud turtles, *Kinosternon subrubrum*, to overwinter on land (Bennett et al. 1970) means that they are more likely to migrate through the land-water interface than is a more aquatic species such as the stinkpot, *Sternotherus odoratus*. Undoubtedly, there are other subtle, important ecological differences among species that affect their respective rates of capture in similar manners.

Certain false impressions about abundance, diversity or behavior of animals in an area can be given by factors related to design of the tapping system, in combination with the ecology of the species involved. One of the most important design factors may be the spatial arrangement of the drift fences (Fig. 1B,C,D). Distance of a fence from a critical habitat, such as an aquatic breeding site or a terrestial denning or nesting area, can greatly influence the number of captures of certain species. The key factor is whether the fence intercepts the path of migration, or other movement, of animals from one site to another. A potential impact of fence placement can be readily seen in the disparity in numbers of certain species that leave or enter from particular directions in a habitat. For example, a partial fence could lead to misinterpretations about the numbers of some species (e. g., *K. subrubrum*) that leave or enter the aquatic area. Extrapolation errors would be less likely to result from other species (e.g., *S. odoratus*) that appear to use the perimeter in a more uniform manner (Table 3).

Table 3. Directional disparities that could result from drift fence placement if partial fencing is used in or around a habitat. Numbers are based on total captures of semi-aquatic turtles in pitfall traps on either side of the fence encircling Ellenton Bay, South Carolina, from 1975 to 1981. The perimeter was arbitrarily partitioned into the four compass directions for Chi-square contingency analysis.

Species	North	East	South	West	Chi-square value
Chelydra serpentina	28	34	24	24	1.29
Sternotherus odoratus	43	40	52	47	0.98
Pseudemys floridana	33	58	44	95	10.86 *
Deirochelys reticularia	101	249	119	273	60.34 **
Pseudemys scripta	162	365	269	228	80.87 **
Kinosternon subrubrum	801	498	204	253	305.48 **
TOTAL	1168	1244	712	920	77.69 **

* $P < .05$
** $P < .01$

The temporal aspect is also critical, not only at the seasonal level but in some instances on a daily basis (e. g. Hurlbert 1969; Gibbons 1970; Semlitsch et al. 1981). Long-term studies reveal that annual disparities can be great enough to provide the potential for improper interpretations if drift fences are used to sample habitats for short periods of time (Gibbons and Bennett 1974: Table 4).

Because of the factors discussed above, a well-constructed and maintained drift fence with pitfall traps will be effective in capturing most individuals of certain species in an area, and none of others. The outstanding number of captures of *A. talpoideum*, as well as the high recapture rate, suggest that the method is highly effective for this pond-breeding, migratory species (Table 5). On the other hand, relatively few adult black racers, *Coluber constrictor* (Table 2), have been captured in pitfall traps on the SRP, although the species is very abundant in the areas under study (Gibbons and Patterson 1978). Not surprisingly, these and other large snakes easily escape from the traps. The same is true of

Table 4. Annual and local variation in total captures of adult amphibian and reptile species commonly sampled in drift fences on the Savannah River Plant, South Carolina. Each sampling year began in September and continued through August.

Site and species	Sampling year		
	1978-79	1979-80	1980-81
Rainbow Bay			
Notophthalmus viridescens	1,271	1,058	772
Scaphiopus holbrooki	51	10	45
Rana utricularia	508	346	475
Kinosternon subrubrum	53	24	23
Cnemidophorus sexlineatus	1	1	3
Tantilla coronata	15	28	8
Sun Bay			
Notophthalmus viridescens	1,757 *	2,745	728
Scaphiopus holbrooki	1,271 *	756	12
Rana utricularia	99 *	79	35
Kinosternon subrubrum	87 *	16	19
Cnemidophorus sexlineatus	19 *	29	12
Tantilla coronata	40 *	50	10

* Minimum estimate

certain species of treefrogs (*Hyla),* which can climb the sides of a bucket or a fence (Gibbons and Bennett 1974). For many large mammals (e. g. raccoon, opossum), no adults have ever been captured in the traps. However, those species for which the technique is either always or never effective are not the primary problems. The major difficulty in interpretation and analysis of data from drift fences results from those species whose captures only partly reflect the numbers of individuals that actually encounter the fence or live in the vicinity. Unless the effectiveness or sampling rate is known, certain conclusions relating to population size or absolute abundance should be drawn with caution. However, the potential for using the technique to estimate larval survivorship, immigration and emigration rates, genetic exchange, and other difficult-to-obtain data, has been demonstrated (Gibbons 1970; Shoop 1974; Gill 1978; Semlitsch and McMillan 1980; Semlitsch 1981) and should not be underestimated.

Merely revealing the presence of a rare species can be a contribution to an understanding of its basic biology. Star-nosed moles, *Condylura cristata*, have been infrequently captured in pitfall traps on the

Table 5. The number of drift fence captures and recaptures of adult *Ambystoma talpoideum* entering and exiting Rainbow Bay, South Carolina. The percentages indicate the increasing effectiveness of the technique for this species as a greater proportion of the population is collected.

	Sampling year		
	1978-79	1979-80	1980-81
Total number entering (marked and unmarked)	459	2,133	450
Total number exiting			
Already marked	193	836	264
Unmarked	70	200	19
Percent of already marked individuals of those entering	42%	39%	59%
Percent of unmarked individuals exiting of those entering	15%	9%	4%
Sampling error (based on assumption that 100% of specimens on inside of fence were marked)	27%	19%	7%

SRP. However, the 14 specimens captured represent a major sample compared to those previously reported from either South Carolina or Georgia in the previous century (Golley 1962, 1966). The findings suggest that the species is not necessarily rare or restricted in its geographic range or habitat preference, but is merely difficult to capture by conventional trapping methods.

Another form of bias is that adults of certain species may not be captured in pitfall traps, although the smaller juveniles may be susceptible and reveal an unexpected abundance. This phenomenon was witnessed with the rainbow snake, *Farancia erytrogramma*, in which more than 100 subadult animals were captured in an area where large adults have never been seen (Gibbons et al. 1977). Such captures must be interpreted cautiously, but their value for certain purposes is obvious.

CONCLUSIONS

Drift fences are capable of collecting large amounts of data on a daily basis over long periods of time (> 5 years). For some species they provide the only effective sampling technique, and for many it is highly cost effective. However, variation in morphology, ecology, and behavior of each species must be considered. If the limitations and biases of the drift fence and pitfall trap technique are considered, population sizes, seasonality, migration patterns, diversity, and distribution of many species of animals can be effectively determined.

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